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Fatigue Life Assessment of Aluminium Alloy 6061 Specimen Using Signal Analysis Approach for Automotive Components

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Abstract: This paper is aimed to investigate the fatigue assessment of aluminium alloy 6061specimen, one of the widely used aluminium alloys in the production of mechanical components. The alloy possesses the ability of critical failure caused by fatigue when they are subjected to dynamic responses in automotive-type components. The specimens were prepared according to the ASTM E606 and ASTM E1820 standards which were then subjected to two types of cyclic loading amplitude modes namely constant amplitude and random amplitude. The effort is initiated by implementing fatigue data editing approach for random amplitude signal, the conventional method, the finite element method (FEM) and fatigue assessment determination through the statistical method of root mean square (r.m.s) and kurtosis. The input and edited signal acquired will be analyzed for the prediction of the fatigue damage based on the strain model approaches, i.e. Coffin-Manson, Morrow and SWT. From the results obtained, both edited and non-edited signals' load display the same amount of fatigue damage to consequently decrease the analysis duration. In addition, the FEM was found to be the best approach for estimating the fatigue life. This research has finally revealed that the higher cyclic load amplitude will only diminish the fatigue life of a specimen. Furthermore, this fatigue assessment study will look forward to improve structural engineering development in monitoring components and consequently access the damage prediction variable which could later be implemented to the manufacturing industry.

Introduction

In material engineering, fatigue failure is caused by repeated loads acting on a machine component or structure. Traditionally, fatigue life is divided into two, which are the initial period and crack growth period [1]. There is indeed no clear percentage to determine mechanical failures, but the literatures suggested that between 50 to 90 percent of mechanical failures are caused merely by fatigue [2].

The objective of time-series analysis is to ultimately determine the statistical characteristics of the original function by manipulating a series of discrete numbers [3]. These discrete numbers will be analyzed using necessary statistical method which can evaluate and assess fatigue damage. This fatigue damage was probably caused by the dynamic responses acting in automotive-type components.

Aluminium alloy 6061 is a precipitation solidifying aluminium alloy, containing magnesium and silicon as its major alloying elements, which have excellent mechanical properties and display good weld ability. Aluminium alloy 6061 is widely used by most industry sectors, especially in manufacturing of aircraft structures, such as fuselage and wings, more commonly in home-built aircraft than military or commercial aircraft [4]. It has been selected for this experiment due to its application in automotive-type components that exhibit cyclic loading and its low cost.

The main objective of this research is to explore the relationship between the signal analysis approach and statistical moment related to fatigue life prediction by using different fatigue assessment methods. This study was conducted on two types of aluminium 6061 specimens in accordance with the dimension found in ASTM E606 and ASTM E120. Two types of repeated load acting as repetitive stress on both specimens are the recurring load of constant amplitude and random amplitude. Fatigue life predictions were accessed by using the conventional method and the FEM. In addition, a statistical approach is also analyzed to predict the behaviour of the signal. Finally, fatigue life predictions were projected via strain-life approach (ε-N) depending on the input signal. As an expected result, statistical parameters of r.m.s and the kurtosis increase in fatigue damage in accordance with the amplitude of the load applied.

Materials and Method

Material. In this analysis, aluminium alloy 6061 is selected, which is normally used in an automotive component due to their relatively excellent mechanical properties and moderately good weld ability. The mechanical property at the room temperature (Metals Handbook 1990) is listed in Table 1 respectively.

Table 1: Mechanical properties of aluminium alloy 6061

Mechanical properties	6061 aluminium alloy
Ultimate Tensile Strength, σ_{utm}[MPa]	125
Yield Strength, σ_y[MPa]	55
Fatigue Endurance Limit[MPa]	60
Young Modulus, E[GPa]	69
Fatigue Strength Coefficient, σ'_f [MPa]	208.75
Fatigue Strength Exponent, b	-0.095
Fatigue Ductility Coefficient, c	-0.69
Fatigue Ductility Exponent, ε'_f	0.35

Signal Analysis. The signal is the physical information about a variable that has been measured and occurs between the processes involved, between the available stages, and most importantly the output of the measurement system [7]. Root mean square value is the second statistical moment. It is used to determine the total energy content of the entire signal [3]. For a set of discrete data (x), root mean square (r.m.s) value is given by the following Eq. 1:

$$r.m.s = \left\{1/n \sum_{j=1}^{n} x_j^2\right\}^{1/2} \quad (1)$$

Kurtosis is a four statistical moment of the signal. It is a global statistical signal which has a high sensitivity of the peaks in a data. Kurtosis is frequently used in engineering to detect the symptoms of damage because it is ultra sensitive to the situation of high-amplitude [3]. Kurtosis value can be obtained through Eq. 2 as follows:

$$K = \frac{1}{n(r.m.s)^4} \sum_{j=1}^{n} \left(x_j - \bar{x}\right)^4 \quad (2)$$

Before data measurement was carried out, geometry of fatigue experiment specimens was produced for finite elemental analysis purpose using Nastran/Patran software to determine the maximum stress location [5]. That stress analysis can determine the maximum damage location when the static load is imposed. Fig. 1 shows four original strain signals that were achieved from experimental measurement data. Long period of time for the original signal amplitude of both types was removed so that only 30,000 points of discrete signals remain. The result of this process is known as the input signal. Method of data editing was done on a random amplitude strain signals only. This is because, editing the data will remove the low amplitude of an input signal that will provide minimal impact on the fatigue failure and sustain high-amplitude cycles [6]. In addition, this method will reduce the time period of the input signal. The minimum block of fatigue damage was removed, and a new block of the output signal which has maximum fatigue damage was produced. This signal is called signal data editing.

Fatigue Life Prediction Method. The signals obtained from the measurement data were used to analyze the finite element model of ASTM E1820 and ASTM E606 specimen. Before the fatigue life analysis is done, both specimens were equipped with the applied loads and boundary conditions for linear elastic analysis. The meshing used was a tetrahedral element with a global long distance side of 0.0025 meters. Tetrahedral elements were used to obtain more precise results because it has a high degree of freedom and robust discretization elements [8]. The nature of this model is set to be homogeneous with a fixed surface, and other surfaces were applied with the load. To complete the analysis of specimens, the input and editing signals were used to determine the lifetime of the specimen. In addition, it can identify the location of the specimen model experiencing maximum stress and strain, which will cause the beginning of the static crack and failure.

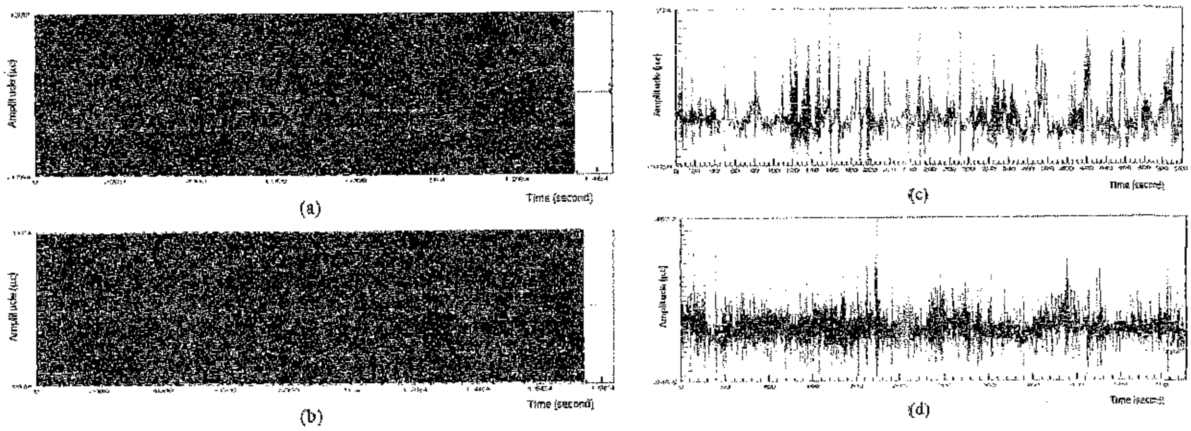

Fig. 1: The original strain signal obtained from the experiments: (a) constant amplitude 1, (b) constant amplitude 2, (c) random amplitude 1, (d) random amplitude 2

Result and Discussion

The analysis of conventional method is to determine fatigue damage in aluminium alloy 6061 according to the amplitude imposed. The results of the simulations carried out are, shown in Table 2 and Table 3, obtained according to the input and editing signal. As displayed in the table, the signal of constant amplitude 2 shows the highest fatigue damage which is 116 x 10^{-6} damage per block using Coffin-Manson approach. This shows that for constant amplitude signal, Coffin-Manson strain model shows a high probability of the most fatigue damage because it did not reflect the average stress correction. For the random amplitude of the signal, amplitude 1 shows the highest value of fatigue damage which is 96.9 x 10^{-6} damage per block using SWT model approach. This value was indicated that the SWT strain model is suitable to determine the fatigue damage occurred by the cyclic tensile loading, which follow the value of amplitude applied.

Fig. 2 and Fig. 3 are plotted to show the relationship between the value of fatigue life against the r.m.s value and kurtosis by using the conventional and FEM. These graphs are created to anticipate the difference in fatigue life between two distinct simulation assessment processes related to signal behaviour. Both graphs show that the fatigue life value of conventional method is higher than the FEM. However, FEM is more appropriate to predict the fatigue life of aluminium alloy 6061 specimens. For the graph of fatigue life against r.m.s, higher r.m.s value indicates a reduction of fatigue life in both methods. This shows that the internal energy is produced based on the prevailing tension and compressibility during the process of perception simulation data. For a graph of fatigue life against kurtosis, the highest value of fatigue life is close to a kurtosis value of 3, which indicates a distribution of the normal Gaussian behaviour on a discrete data. However, a high kurtosis value would indicate that there are many extreme values on the Gaussian distribution. Thus, according to the relationship, statistic method by using r.m.s and kurtosis may be used to predict fatigue life of aluminium alloy 6061.

The fatigue analysis was performed using three strains approach, which are Coffin-Manson, Morrow and SWT on the discrete data obtained. Coffin-Manson approach was used to more precisely define the constant amplitude fatigue damage, which shows that the percentage reduction in fatigue life is 0.52% to 0.76% more accurate. Meanwhile, the SWT approach was used to determine fatigue damage on the amplitude of random experience percent reduction in fatigue life, which is 0.26% to 0.43%. The relationship between the signal behaviour and fatigue life can be expressed in statistics in which, a high r.m.s value indicates high fatigue damage and shorting the fatigue life. The relationship between the root mean square is proportional to the fatigue damage, and this relationship can also be used in the application of statistical behaviour of the kurtosis. In addition, the results of lower fatigue life obtained from the FEM compared to the conventional method show indication of the fatigue life more accurately. This is because, the result of FEM is influenced by geometry, applied loads and material used to produce these components, while the results of the conventional methods are affected only by the material and applied loads.

Table 2: Fatigue damage input signal according to strain life model

Type of Amplitude	Fatigue Damage (damage per block)		
	Morrow	SWT	Coffin-Manson
Uniform Amplitude 1	88.4×10^{-6}	55.4×10^{-6}	116×10^{-6}
Uniform Amplitude2	73.8×10^{-6}	28.6×10^{-6}	121×10^{-6}
Random Amplitude1	75.1×10^{-6}	96.9×10^{-6}	55.6×10^{-6}
Random Amplitude2	33.0×10^{-6}	38.2×10^{-6}	28.1×10^{-6}

Table 3: Fatigue damage editing signal complementing the strain life model

Type of Amplitude	Fatigue Damage (damage per block)		
	Morrow	SWT	Coffin-Manson
Random Amplitude 1	75.1×10^{-6}	96.9×10^{-6}	56.4×10^{-6}
Random Amplitude 2	32.9×10^{-6}	38.2×10^{-6}	28.1×10^{-6}

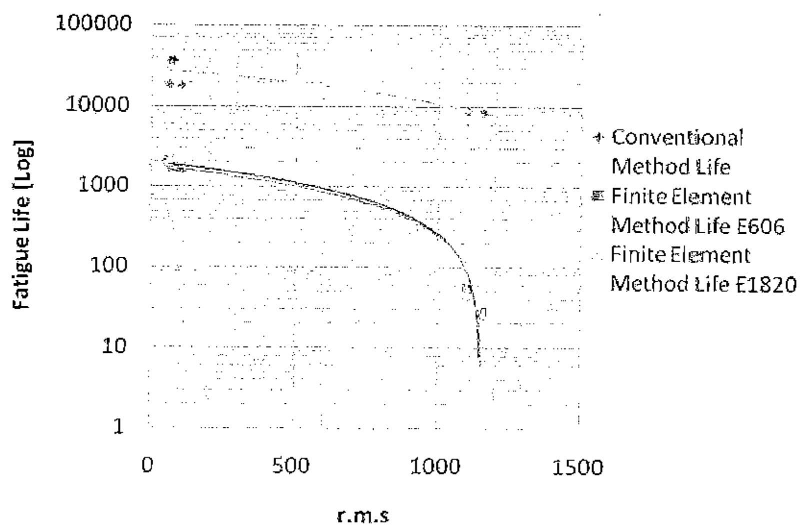

Fig. 2: Graph of fatigue life (log) versus the root mean square (r.m.s)

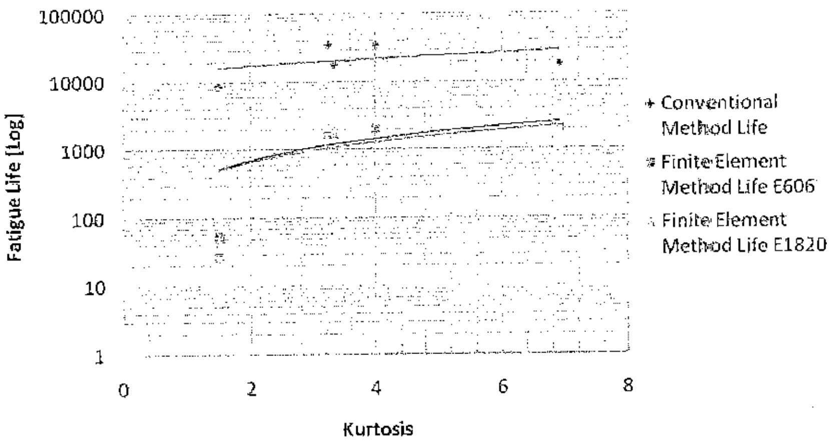

Fig. 3: Graph of fatigue life (log) versus the kurtosis

Conclusion

Simulation study was conducted on the fatigue life assessment of aluminium alloy 6061 specimens under two types of loading; constant and random. All strain signals were analysed and have been linked to statistical moment which are r.m.s and kurtosis. The r.m.s and kurtosis values were obtained to observed the trend and behaviour correlating to fatigue life assessment method; conventional and FEM. For both loading, higher r.m.s value will decrease the value of fatigue life towards failure while higher kurtosis value will indicate there are many peak produce in the strain signal itself. This will explain a significant relation of loading applied to the fatigue life assessment. The edited and non edited strain signal produce the same fatigue life result shows that the fatigue damage only was affected by the high cycle of amplitude. As conclusion, this research has finally exposed that the higher cyclic load amplitude will only decrease the fatigue life of a specimen, and the FEM was found to be the best access for valuation the fatigue life.

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